Fermilab

UPC 118

FIELD FLATNESS OF DOUBLER DIPOLES

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I. Introduction

Acceptance criteria for the field quality of doubler dipoles have been set up for multipole components up to and including the decapole. In addition, criteria for $|\Delta B_y/B_o|$ and $|B_x/B_o|$ on the median plane at $x = \pm 0.5"$ and $\pm 1"$ have been in use so far. These criteria on the overall flatness of dipoles are based on a purely pragmatic reasoning and do not come from requirements of beam dynamics. If a dipole satisfied all criteria on multipole components but did not meet the flatness criteria, this magnet would be installed at a place where both β_h and the momentum dispersion parameter are small. The practice up to now has been to be firm but flexible and reasonable in judging each magnet for the final acceptance. Admittedly, the procedure is partially subjective and the final decision inevitably depends on many factors.

The question of field flatness has been brought up by Alvin Tollestrup and Tom Collins recently and there was a meeting (December 11th) to discuss this somewhat ambiguous matter. It was clear (to me at least) that they entertained a possibility of momentum stacking in addition to the desirability of having a flexibility to move the beam in and out. Once we start taking this seriously, we may have to reevaluate the correction system or we may have to demand doubler dipoles of much better field quality. Neither prospect is a welcome thing for us at this time and the final decision can be made only by the PMG. The purpose of this note is to present available data on the question of flatness or, equivalently, data on the <u>local</u> multipole fields. After some discussions at the meeting on December 11th, it was more or less agreed that we should look at the field errors at $\pm 0.8"$ and the local field gradients at $\pm 0.5"$.

In evaluating the field, the contributions from the quadrupole (normal and skew) and the normal sextupole components will not be included since they are expected to be compensated for by the correction system,

$$b_1 = b_2 = a_1 = 0.$$

The momentum stacking proposed by T. Collins[1,2] expects $\Delta p/p = \pm 0.2\%$ with the maximum value of dispersion parameter at around 10 m. Therefore, the beam can be at $x = \pm 0.8''$ but the average radial beam position in dipoles will be $3\text{m}\times(\pm 0.2\%) \simeq \pm 0.25''$.

It is difficult to define the boundary of the area within the bore tube in which the beam should survive. If the momentum stacking is the only consideration, one would look at local field errors, local field gradients and, possibly, local sextupole fields within $x \simeq \pm 0.3''$ and $y \simeq \pm 0.15''$. For this case, skew sextupole and octupole fields will be the dominant components and the addition of corresponding correction system will improve the field substantially. If the area of our interest extends to $x = \pm 0.8''$, higher-order natural multipoles (14-poles, 18-poles, etc.) will make significant contributions and one may get the impression that the addition of skew sextupole or normal octupole correction system makes very little difference. One may even begin to contemplate a correction system which is not based on the multipole decomposition (something similar to the ISR system). The "proper" value of y is even more difficult to decide. Ordinarily, one would not think of a closed orbit which is displaced vertically by 0.5"; if one must consider the stability of such an orbit, many new problems would come up and the whole thing is likely to be an entirely new ball game. I mention these points before presenting data so that we are all aware of pitfalls associated with the interpretation of data. If a decision to do (or not to do) something is to be made based on the data, that decision must necessarily be of a soul-searching nature.

II. Data

Data from forty-one dipoles have been used and the dipoles are:

1. accepted (16)	207	210	211	213	214	215	222	224	226
	233	234	235	236	238	241	242		
2. rejected (6)	200	218	219	221	223	239			
3. undecided (13)	201	203*	216	217	220	237	243	244	245
	246	249	254	256					
4. long cryostat (6)	202	203*	204	205	206	208			

*TA0203 is counted twice, with a long and a short cryostat.

normal field:	$b_y \equiv (B_y - B_o)/B_o$	in 10^{-4}
skew field:	$b_x \equiv B_x/B_o$	in 10^{-4}
normal gradient	$b'_y \equiv \partial b_y/\partial x$	in 10^{-4}/inch
skew gradient	$b'_x \equiv \partial b_x/\partial x$	in 10^{-4}/inch

All data are at (nominal) 4,000A and $b_1=b_2=a_1=0$ is always assumed. It is possible to accumulate many tables and figures but the following cases are presented here:

Table 1. $x = \pm 0.8"$, $y = 0$ with and without correction for a_2 (skew sextupole field); 41 dipoles.

Table 2. same as Table 1, 16 accepted dipoles only.

Table 3. $x = \pm 0.5"$, $y = 0$, otherwise same as Table 1.

Table 4. same as Table 3, 16 accepted dipoles only.

Table 5. $x = \pm 0.5"$, $y = 0.25"$, otherwise same as Table 1.

Table 6. same as Table 5, 16 accepted dipoles only.

Table 7. $x = \pm 0.3"$, $y = 0$; effects of b_3, b_4, a_2, a_3 and a_4; 41 dipoles.

Table 8. same as Table 7, 16 accepted dipoles only.

Quantities listed in each row are:

1. average value
2. standard deviation
3. number of magnets beyond one standard deviation
4. number of magnets beyond two standard deviations

III. Comments

Tom Collins commented that, in establishing criteria on the field flatness, there should be some guidelines based on the beam dynamics instead of relying exclusively on pragmatic considerations. If the ideal closed orbit with $\Delta p/p \neq 0$ is considered to be on the median plane ($y = 0$), effects of b_y, b_x, $\partial b_y/\partial x$ and $\partial b_x/\partial x$ on the closed orbit can be estimated in the conventional manner. It will be particularly instructive to compare the field quality at various values of $x \neq 0$ (with the correction $b_1=b_2=a_1=0$) with the field quality at $x = 0$ without any correction.[3]

1) average b_y

This shifts the closed orbit as a whole radially. The effect is very small even at $x = \pm 0.8"$.

2) average b_x

With $b_x = 1$, the maximum vertical excursion of the orbit is 0.68mm and the rms excursion is 0.34mm. The effect is negligible since $|(b_x)_{av}| < 0.7$ for $|x| < 0.8"$.

3) fluctuations in b_y and b_x

Expected closed-orbit distortions are (assuming $\nu = 19.4$)

$$\text{radial:} \quad \langle\Delta x\rangle = 9.0\text{m}\times\langle b_y\rangle \quad \text{at } \beta_h = 100\text{m},$$

$$\text{vertical:} \quad \langle\Delta y\rangle = 9.1\text{m}\times\langle b_x\rangle \quad \text{at } \beta_v = 100\text{m}.$$

By taking twice the rms value, one can probably gain (80∿85)% confidence level. The distortions may not be entirely negligible at $x = \pm 0.8"$ but they are certainly very small at $x = \pm 0.5''$ or less.

4) average $\partial b_y/\partial x$

The corresponding parameter at $x = 0$ is b_1 (normal quadrupoles) and it is approximately -1 (without any correction). It is possible that the average value of $\partial b_y/\partial x$ would change somewhat as we continue to accumulate the dipoles. Nevertheless, the tune shifts are large at $|x| > 0.5''$. They are safe at $x = \pm 0.3''$.

$$\Delta\nu_x = 0.11 \times (\partial b_y/\partial x)_{av}\ ,\quad \Delta\nu_y = -0.12 \times (\partial b_y/\partial x)_{av}$$

5) fluctuation in $\partial b_y/\partial x$

This drives the resonances $2\nu_x = n$ and $2\nu_y = n$. At $x = 0$ without any correction,

$$(\partial b_y/\partial x)_{std.dev.} \rightarrow (b_1)_{std.dev.} = 1.47 \text{ (at 4,000A)}$$

The corresponding full resonance width (rms) is 0.013. This is similar to the situation at $x = \pm 0.5''$ with the correction for b_1, b_2 (a_1 is immaterial). With $y = 0.25''$, the width becomes twice as large.

6) average $\partial b_x/\partial x$

This drives the resonance $\nu_x - \nu_y = 0$. At $x = 0$ without any correction,

$$(\partial b_x/\partial x)_{av} \rightarrow (a_1)_{av} = -0.27 \text{ (500A) to } 0.12 \text{ (4,000A)}$$

Although there will be a sizable coupling even at $x = \pm 0.3''$, this resonance by itself should not be too harmful to the beam.

7) fluctuation in $\partial b_x/\partial x$

This drives the resonance $\nu_x + \nu_y = n$. At $x = 0$ without any correction,

$$(\partial b_x/\partial x)_{std.\ dev.} \rightarrow (a_1)_{std.\ dev.} = 1.9 \text{ (4,000A)}$$

Again this is more or less what we have at $x = \pm 0.5''$ with the correction for a_1 (b_n corrections immaterial).

The impression one gets from these data is that the beam will survive if the closed orbit is confined to $|x| < 0.3"$ and $|y| < 0.2"$. If we are lucky, this may be extended to $|x| \simeq 0.5"$ but definitely not more than that. From Tables 7 and 8, one sees that the addition of skew sextupole correction alone cannot extend the area. Order-of-magnitude improvements are possible with b_4 (normal decapole) and a_3 (skew octupole) corrections. This is more than I anticipated in the Introduction.

References

1. T. L. Collins, UPC No. 23, December 13, 1978.

2. "A Report on the Design of the Fermi National Accelerator Laboratory Superconducting Accelerator", May 1979, 182 - 183.

3. S. Ohnuma, TM-910, October 15, 1979.

Table 1. x = ±0.8", y = 0; with and without correction for a_2 (skew sextupoles); 41 dipoles.

$a_2 \neq 0$

SAMPLE NUMBER = 41

X & Y:	0.80	0.00 INCH		
BY:	-0.5255	0.8709	14	2
BX:	-0.6544	1.4883	8	3
BYP:	-8.7114	4.2241	16	3
BXP:	-1.5425	5.6659	10	3

$a_2 = 0$

SAMPLE NUMBER = 41

X & Y:	0.80	0.00 INCH		
BY:	-0.5255	0.8709	14	2
BX:	-0.2870	1.3205	10	2
BYP:	-8.7114	4.2241	16	3
BXP:	-0.6240	5.4193	12	2

$a_2 \neq 0$

SAMPLE NUMBER = 41

X & Y:	-0.80	0.00 INCH		
BY:	0.0999	1.0045	15	2
BX:	-0.2103	1.6476	10	2
BYP:	5.9670	4.7322	16	1
BXP:	0.7046	6.0797	10	3

$a_2 = 0$

SAMPLE NUMBER = 41

X & Y:	-0.80	0.00 INCH		
BY:	0.0999	1.0045	15	2
BX:	0.1570	1.3885	9	2
BYP:	5.9670	4.7322	16	1
BXP:	-0.2139	5.6254	9	2

Table 2. same as Table 1, 16 accepted dipoles only.

$a_2 \neq 0$

SAMPLE NUMBER = 16

X & Y:	0.80	0.00 INCH		
BY:	-0.3135	0.9204	4	0
BX:	-0.4911	1.7212	3	1
BYP:	-7.6025	4.2993	5	0
BXP:	-1.0746	6.3235	6	1

$a_2 = 0$

SAMPLE NUMBER = 16

X & Y:	0.80	0.00 INCH		
BY:	-0.3135	0.9204	4	0
BX:	-0.3177	1.3771	5	1
BYP:	-7.6025	4.2993	5	0
BXP:	-0.6411	5.6209	6	1

$a_2 \neq 0$

SAMPLE NUMBER = 16

X & Y:	-0.80	0.00 INCH		
BY:	0.1470	0.8701	5	1
BX:	0.1225	1.4476	3	2
BYP:	5.7168	4.2143	5	0
BXP:	-0.4302	5.7140	3	2

$a_2 = 0$

SAMPLE NUMBER = 16

X & Y:	-0.80	0.00 INCH		
BY:	0.1470	0.8701	5	1
BX:	0.2959	1.4159	3	1
BYP:	5.7168	4.2143	5	0
BXP:	-0.8637	5.7970	3	1

Table 3. $x = \pm 0.5''$, $y = 0$; with and without correction for a_2 (skew sextupoles); 41 dipoles.

$a_2 \neq 0$

SAMPLE NUMBER = 41

X & Y:	0.50	0.00 INCH		
BY:	0.0308	0.1524	14	2
BX:	-0.2215	0.4079	8	3
BYP:	0.3213	1.1078	16	2
BXP:	-1.0667	2.1446	8	3

$a_2 = 0$

SAMPLE NUMBER = 41

X & Y:	0.50	0.00 INCH		
BY:	0.0308	0.1524	14	2
BX:	-0.0780	0.3028	9	2
BYP:	0.3213	1.1078	16	2
BXP:	-0.4927	1.8570	10	2

$a_2 \neq 0$

SAMPLE NUMBER = 41

X & Y:	-0.50	0.00 INCH		
BY:	0.1618	0.1789	14	2
BX:	-0.0911	0.4565	12	3
BYP:	-1.1595	1.2937	15	1
BXP:	0.2810	2.3986	10	2

$a_2 = 0$

SAMPLE NUMBER = 41

X & Y:	-0.50	0.00 INCH		
BY:	0.1618	0.1789	14	2
BX:	0.0524	0.3162	9	[illegible]
BYP:	-1.1595	1.2937	15	1
BXP:	-0.2931	1.9570	9	2

Table 4. same as Table 3, 16 accepted dipoles only.

$a_2 \neq 0$

SAMPLE NUMBER = 16

X & Y:	0.50	0.00 INCH		
BY:	0.0674	0.1690	5	0
BX:	-0.1565	0.4798	3	1
BYP:	0.5800	1.1991	4	0
BXP:	-0.8249	2.5127	3	1

$a_2 = 0$

SAMPLE NUMBER = 16

X & Y:	0.50	0.00 INCH		
BY:	0.0674	0.1690	5	0
BX:	-0.0888	0.3182	3	1
BYP:	0.5800	1.1991	4	0
BXP:	-0.5539	1.9484	5	1

$a_2 \neq 0$

SAMPLE NUMBER = 16

X & Y:	-0.50	0.00 INCH		
BY:	0.1647	0.1522	5	1
BX:	0.0091	0.3755	4	1
BYP:	-1.2119	1.0960	5	1
BXP:	-0.1978	2.0623	3	2

$a_2 = 0$

SAMPLE NUMBER = 16

X & Y:	-0.50	0.00 INCH		
BY:	0.1647	0.1522	5	1
BX:	0.0768	0.3226	2	1
BYP:	-1.2119	1.0960	5	1
BXP:	-0.4687	1.9865	2	1

Table 5. x = ±0.5", y = 0.25"; with and without correction for a_2 (skew sextupoles); 41 dipoles.

$a_2 \neq 0$

SAMPLE NUMBER = 41

X & Y:	0.50	0.25 INCH		
BY:	0.1614	0.5040	9	2
BX:	0.0165	0.3007	14	3
BYP:	1.3501	2.0880	12	3
BXP:	0.8894	2.2118	9	3

$a_2 = 0$

SAMPLE NUMBER = 41

X & Y:	0.50	0.25 INCH		
BY:	0.0179	0.4218	10	[illegible]
BX:	0.1241	0.2419	13	[illegible]
BYP:	1.0631	1.9954	11	[illegible]
BXP:	1.4635	1.9935	12	2

$a_2 \neq 0$

SAMPLE NUMBER = 41

X & Y:	-0.50	0.25 INCH		
BY:	-0.1530	0.5658	10	3
BX:	-0.3992	0.3190	12	1
BYP:	-0.9341	2.3189	10	2
BXP:	3.0206	2.4556	11	3

$a_2 = 0$

SAMPLE NUMBER = 41

X & Y:	-0.50	0.25 INCH		
BY:	-0.0095	0.4479	8	[illegible]
BX:	-0.2915	0.2656	14	[illegible]
BYP:	-1.2212	2.1432	9	[illegible]
BXP:	2.4465	2.1867	14	[illegible]

Table 6. same as Table 5, 16 accepted dipoles only.

$a_2 \neq 0$

SAMPLE NUMBER = 16

X & Y:	0.50	0.25 INCH		
BY:	0.0976	0.5950	3	1
BX:	0.1227	0.3342	3	0
BYP:	1.3914	2.4120	4	1
BXP:	1.4400	2.5178	3	1

$a_2 = 0$

SAMPLE NUMBER = 16

X & Y:	0.50	0.25 INCH		
BY:	0.0299	0.4559	2	1
BX:	0.1735	0.2535	5	0
BYP:	1.2560	2.1986	4	1
BXP:	1.7109	2.0872	5	1

$a_2 \neq 0$

SAMPLE NUMBER = 16

X & Y:	-0.50	0.25 INCH		
BY:	-0.0544	0.4789	3	1
BX:	-0.3542	0.3163	4	1
BYP:	-1.2865	2.0059	3	2
BXP:	2.7720	2.3179	4	1

$a_2 = 0$

SAMPLE NUMBER = 16

X & Y:	-0.50	0.25 INCH		
BY:	0.0134	0.4556	2	1
BX:	-0.3034	0.2380	4	1
BYP:	-1.4220	2.0612	2	1
BXP:	2.5010	2.1475	4	2

$b_1, b_2, a_1 = 0$
SAMPLE NUMBER = 41

X & Y:	0.30	0.00 INCH		
BY:	-0.0032	0.0260	16	1
BX:	-0.0671	0.1192	7	3
BYP:	0.0193	0.2922	16	1
BXP:	-0.5062	0.9213	8	3

$b_1, b_2, b_3, a_1 = 0$
SAMPLE NUMBER = 41

X & Y:	0.30	0.00 INCH		
BY:	0.0096	0.0164	17	1
BX:	-0.0671	0.1192	7	3
BYP:	0.1469	0.2180	17	1
BXP:	-0.5062	0.9213	8	3

$b_1, b_2, b_3, b_4, a_1 = 0$
SAMPLE NUMBER = 41

X & Y:	0.30	0.00 INCH		
BY:	0.0037	0.0010	13	2
BX:	-0.0671	0.1192	7	3
BYP:	0.0688	0.0169	14	2
BXP:	-0.5062	0.9213	8	3

$b_1, b_2, a_1, a_2 = 0$

X & Y:	0.30	0.00 INCH		
BY:	-0.0032	0.0260	16	1
BX:	-0.0154	0.0644	8	3
BYP:	0.0193	0.2922	16	1
BXP:	-0.1618	0.6468	8	3

$b_1, b_2, a_1, a_2, a_3 = 0$

X & Y:	0.30	0.00 INCH		
BY:	-0.0032	0.0260	16	1
BX:	-0.0020	0.0044	10	2
BYP:	0.0193	0.2922	16	1
BXP:	-0.0276	0.0626	10	2

$b_1, b_2, a_1, a_2, a_3, a_4 = 0$

X & Y:	0.30	0.00 INCH		
BY:	-0.0032	0.0260	16	1
BX:	-0.0004	0.0019	15	2
BYP:	0.0193	0.2922	16	1
BXP:	-0.0063	0.0316	15	2

$b_1, b_2, a_1 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0233	0.0301	11	3
BX:	-0.0396	0.1311	11	3
BYP:	-0.2913	0.3419	13	3
BXP:	0.2271	1.0295	12	3

$b_1, b_2, b_3, a_1 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0106	0.0166	16	1
BX:	-0.0396	0.1311	11	3
BYP:	-0.1637	0.2217	16	1
BXP:	0.2271	1.0295	12	3

$b_1, b_2, b_3, b_4, a_1 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0047	0.0011	10	2
BX:	-0.0396	0.1311	11	3
BYP:	-0.0855	0.0201	10	2
BXP:	0.2271	1.0295	12	3

$b_1, b_2, a_1, a_2 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0233	0.0301	11	3
BX:	0.0121	0.0662	9	3
BYP:	-0.2913	0.3419	13	3
BXP:	-0.1173	0.6707	9	3

$b_1, b_2, a_1, a_2, a_3 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0233	0.0301	11	3
BX:	-0.0013	0.0041	16	1
BYP:	-0.2913	0.3419	13	3
BXP:	0.0170	0.0572	16	0

$b_1, b_2, a_1, a_2, a_3, a_4 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0233	0.0301	11	3
BX:	0.0003	0.0018	15	2
BYP:	-0.2913	0.3419	13	3
BXP:	-0.0043	0.0303	15	2

Table 7. $x = \pm 0.3"$, $y = 0$; effects of higher-multipole corrections. 41 dipoles.

$b_1, b_2, a_1 = 0$

SAMPLE NUMBER = 16

X & Y:	0.30	0.00 INCH		
BY:	0.0031	0.0295	5	1
BX:	-0.0423	0.1357	3	1
BYP:	0.0902	0.3283	5	0
BXP:	-0.3482	1.0821	3	1

$b_1, b_2, b_3, a_1 = 0$

SAMPLE NUMBER = 16

X & Y:	0.30	0.00 INCH		
BY:	0.0122	0.0149	5	0
BX:	-0.0423	0.1357	3	1
BYP:	0.1818	0.1987	5	0
BXP:	-0.3482	1.0821	3	1

$b_1, b_2, b_3, b_4, a_1 = 0$

SAMPLE NUMBER = 16

X & Y:	0.30	0.00 INCH		
BY:	0.0037	0.0009	4	1
BX:	-0.0423	0.1357	3	1
BYP:	0.0678	0.0160	5	1
BXP:	-0.3482	1.0821	3	1

$b_1, b_2, a_1, a_2 = 0$

X & Y:	0.30	0.00 INCH		
BY:	0.0031	0.0295	5	1
BX:	-0.0179	0.0677	3	1
BYP:	0.0902	0.3283	5	0
BXP:	-0.1856	0.6808	3	1

$b_1, b_2, a_1, a_2, a_3 = 0$

X & Y:	0.30	0.00 INCH		
BY:	0.0031	0.0295	5	1
BX:	-0.0014	0.0053	4	0
BYP:	0.0902	0.3283	5	0
BXP:	-0.0213	0.0751	4	0

$b_1, b_2, a_1, a_2, a_3, a_4 = 0$

X & Y:	0.30	0.00 INCH		
BY:	0.0031	0.0295	5	1
BX:	-0.0007	0.0022	6	0
BYP:	0.0902	0.3283	5	0
BXP:	-0.0110	0.0367	6	0

$b_1, b_2, a_1 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0224	0.0265	5	1
BX:	-0.0081	0.1065	3	1
BYP:	-0.2900	0.2931	5	1
BXP:	-0.0011	0.8385	4	1

$b_1, b_2, b_3, a_1 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0132	0.0147	5	1
BX:	-0.0081	0.1065	3	1
BYP:	-0.1984	0.1946	5	1
BXP:	-0.0011	0.8385	4	1

$b_1, b_2, b_3, b_4, a_1 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0047	0.0013	4	0
BX:	-0.0081	0.1065	3	1
BYP:	-0.0844	0.0230	4	0
BXP:	-0.0011	0.8385	4	1

$b_1, b_2, a_1, a_2 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0224	0.0265	5	1
BX:	0.0162	0.0681	2	1
BYP:	-0.2900	0.2931	5	1
BXP:	-0.1636	0.6869	2	1

$b_1, b_2, a_1, a_2, a_3 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0224	0.0265	5	1
BX:	-0.0002	0.0044	4	1
BYP:	-0.2900	0.2931	5	1
BXP:	0.0007	0.0609	4	1

$b_1, b_2, a_1, a_2, a_3, a_4 = 0$

X & Y:	-0.30	0.00 INCH		
BY:	0.0224	0.0265	5	1
BX:	0.0006	0.0021	6	0
BYP:	-0.2900	0.2931	5	1
BXP:	-0.0097	0.0354	6	0

Table 8. x = ±0.3", y = 0; effects of higher-multipole corrections. 16 accepted dipoles only.

Fermilab

Addendum to "FIELD FLATNESS OF DOUBLER DIPOLES"

S. Ohnuma
December 27, 1979

The second meeting to discuss the subject was held on December 21st. Although the importance of normal decapole and skew octupole was generally recognized, there was no conclusion as to what we should do to enlarge the usable aperture of dipoles. Since the condition $b_4=a_3=0$ cannot be realized with the addition of correction magnets, the desirability of making detailed numerical computations with a realistic correction system became clear during the discussion. The computer program developed by Al Russell can handle the problem and any decision on our future plans should be made after his results became available.

The purpose of this addendum is to supplement the statistical information given in UPC No. 118 in order to clarify two questions raised in the second meeting. The first is the field quality of the ideal dipole ("Snowdon dipole") and the second is the improvement one can expect from the b_4 and a_3 corrections beyond 0.3".

A. Ideal Dipoles

The following numbers are based on the information given in the Design Report (May 1979), p. A23, "Integrated Multipole Structure of E-Series Dipole", calculation mode = 1:

$$a_n = b_{2n+1} = 0$$

$b_2= 0.039$	$b_4= 1.037$	$b_6= 4.435$
$b_8= -12.09$	$b_{10}= 3.634$	$b_{12}= -0.822$
$b_{14}= 0.069$	$b_{16}= 0.031$	$b_{18}= -0.044$

The unit for b_n is $10^{-4}/(\text{inch})^n$.

Multipoles are apparently chosen such that the "flat" field extends to $\sim 0.8"$. In achieving this, the nonlinear field $\Delta B_y(y=0)$ is made to vanish at $|x| = 0.78"$ by balancing contributions from various multipoles. The local gradient $\partial B_y/\partial x$ on the median plane, which is an odd function of x, is positive for $x < 0.66"$ and negative beyond that. As a consequence, if one is interested in the field and the gradient for $|x| < 0.5"$, the contribution from b_4 (which is designed to be non-zero) to the local gradient is not entirely negligible and one would rather like to have $b_4 = 0$. Fig. 1 shows ΔB_y and $\partial B_y/\partial x$ on the median plane with $b_4 = 1.04 \times 10^{-4}/\text{in}^2$ and with $b_4 = 0$. For example, at $x = 0.5"$,

if $b_4 = 1.04\times10^{-4}/\text{in}^2$,

$$\partial B_y/\partial x = 0.70\times10^{-4} B_o/\text{in}, \qquad \Delta\nu = \pm0.08$$

if $b_4 = 0$,

$$\partial B_y/\partial x = 0.18\times10^{-4} B_o/\text{in}, \qquad \Delta\nu = \pm0.02.$$

Beyond $|x| = 0.62"$, the ideal dipole is superior to the one with $b_4=0$ if the resulting $\Delta\nu$ is used as the criterion. If $|\Delta B_y|$ is used, it is better beyond $|x| = 0.73"$. Presumably, as we accumulate dipoles, the average value of b_4 will approach the design value*. If the game is to improve the field quality for $|x| < 0.6"$, one may conclude that a correction system is needed to make $b_4 = 0$. On the other hand, the spirit of the design, which is completely justifiable, was to make the field flat as much as possible to $|x| \simeq 0.8"$ and $b_4 = 1.04$ is a consequence of this design philosophy. I must again emphasize the point that, unless we have a definite idea on what we want, arguments on the field flatness will be meaningless. One cannot play a game without knowing its rules.

B. Improvement with $b_4 = 0$ and $a_3 = 0$ beyond 0.3"

Fig. 2A. average value of $\Delta B_y(y=0)$

There is no effect coming from $b_4=0$. Note that, up to 0.7",

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* For 16 accepted dipoles, $(b_4)_{av} = 1.334(500A), 1.312(1,000A)$, and $1.056(4,000A)$.

$(\Delta B_y)_{av}$ is <u>less</u> than what one should expect from the ideal dipole (see Fig. 1, upper figure).

Fig. 2B. average value of $B_x(y=0)$
Effect of $a_3=0$ is substantial to x=0.8".

Fig. 3A. average value of $\partial B_y/\partial x$ (y=0)
No effect from $b_4 = 0$. Again the situation is better than the ideal case up to $x \simeq 0.6"$ (see Fig. 1, lower figure).

Fig. 3B. average value of $\partial B_x/\partial x$ (y=0)
Effects of $a_3=0$ are substantial to x = 0.8".

Fig. 4A. standard deviation of $\Delta B_y(y=0)$
Fig. 4B. " $B_x(y=0)$
Fig. 5A. " $\partial B_y/\partial x$ (y=0)
Fig. 5B. " $\partial B_x/\partial x$ (y=0)

One may conclude from these figures that, with $b_4=0$ and $a_3=0$, the field flatness is extended from 0.3" to (0.6"∿0.7").

<u>Can we tighten the criteria for b_4 and /or a_3?</u>

Here I use 42 dipoles (one recently measured dipole added). If all other criteria are disregarded and

1. if $|a_3| < 2$ is <u>strictly</u> enforced, 30 pass
2. if $|a_3| < 1$ " , 14 pass
3. if $|b_4 - 1.| < 2$ " , 26 pass
4. if $|b_4 - 1.| < 1$ " 12 pass
5. if $|a_3| < 2$ <u>and</u> $|b_4 - 1.| < 2$ " , 16 pass
6. if $|a_3| < 1$ <u>and</u> $|b_4 - 1.| < 1$ " , 2 pass

What conclusion should be drawn from these numbers is not a very difficult question, I believe.

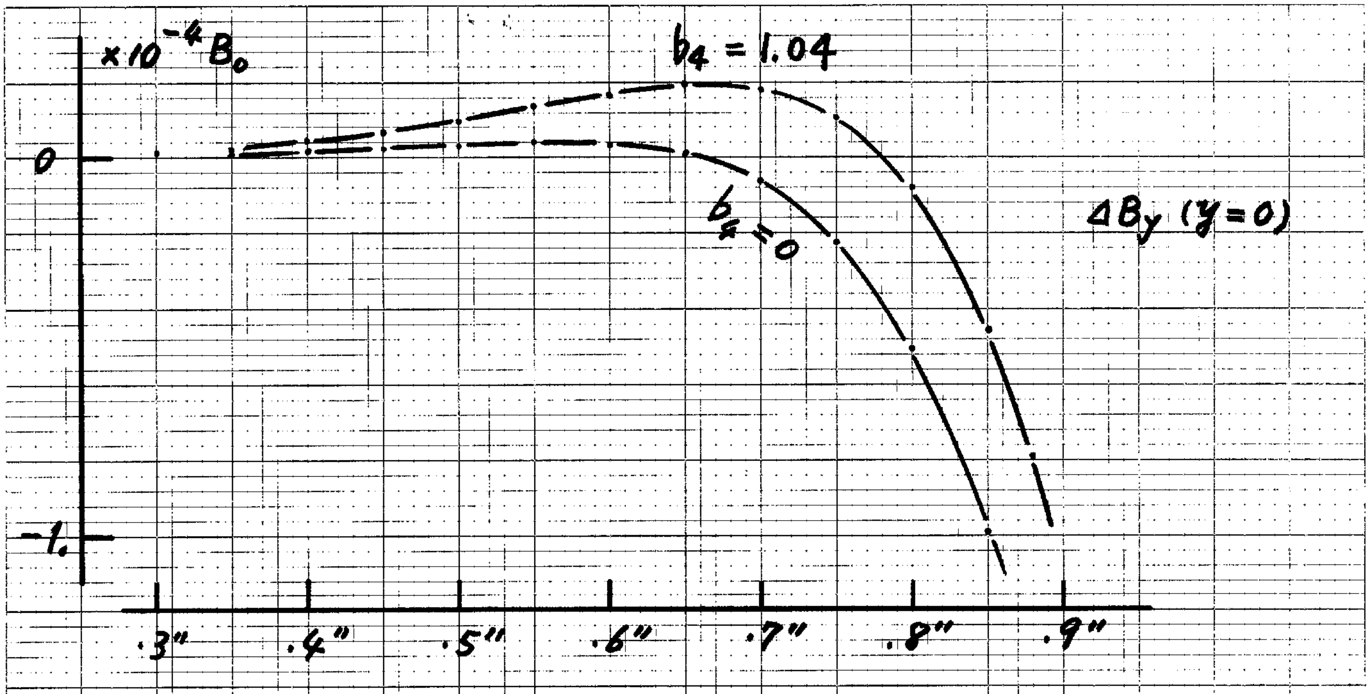
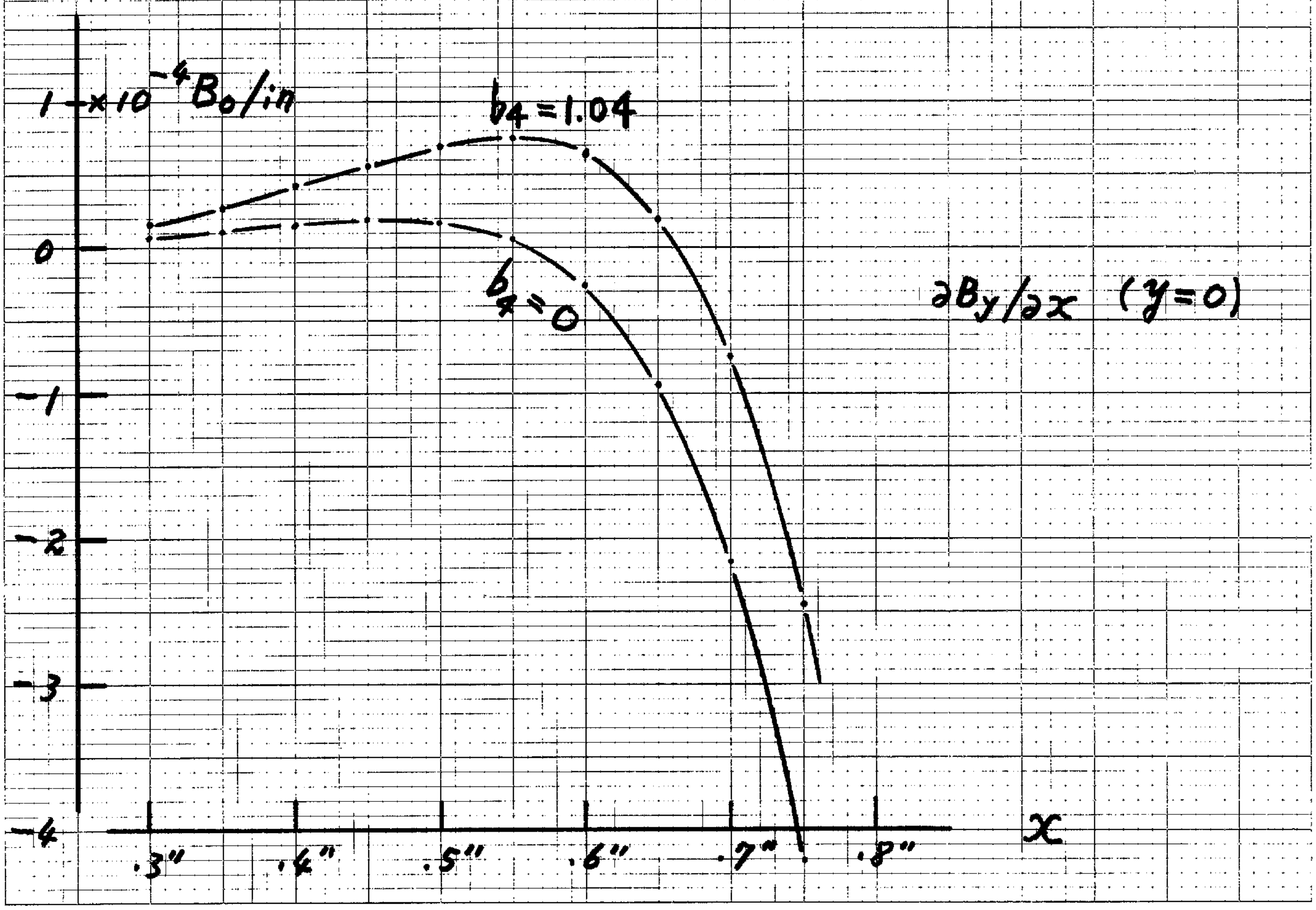


Fig. 1. Ideal (Snowdon) Dipole



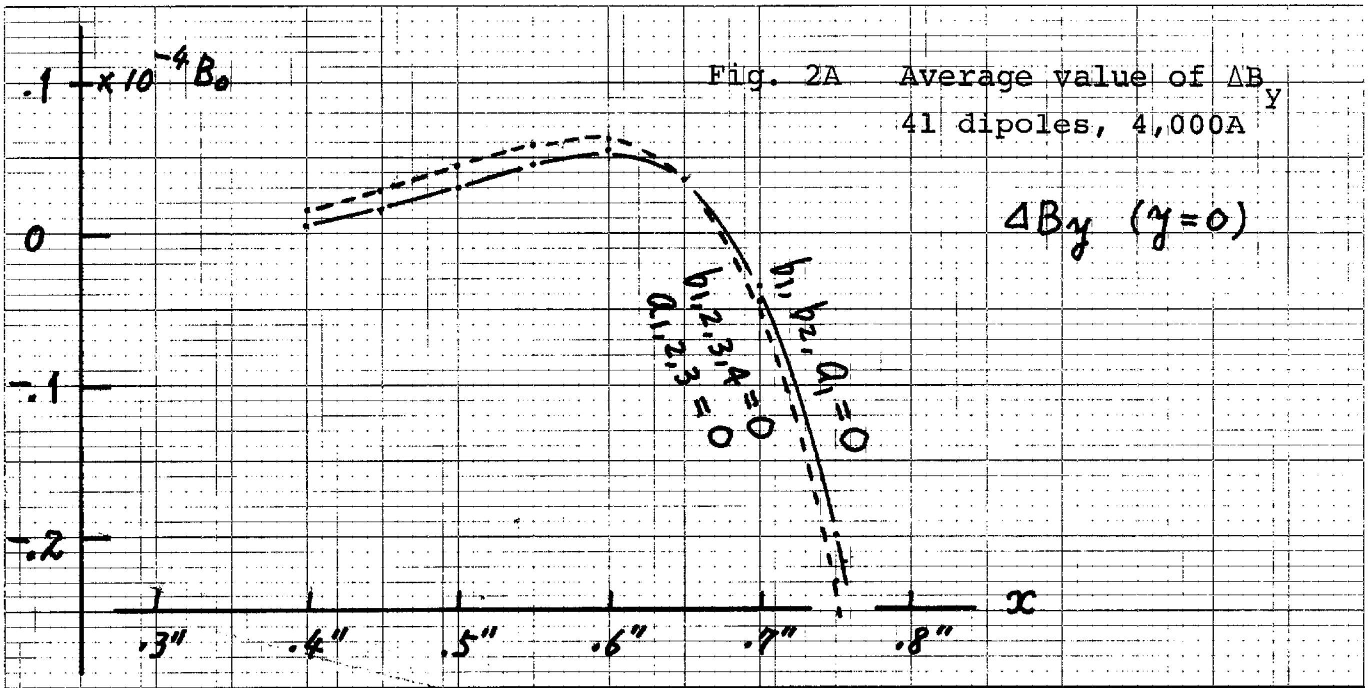


Fig. 2A Average value of ΔB_y
41 dipoles, 4,000A

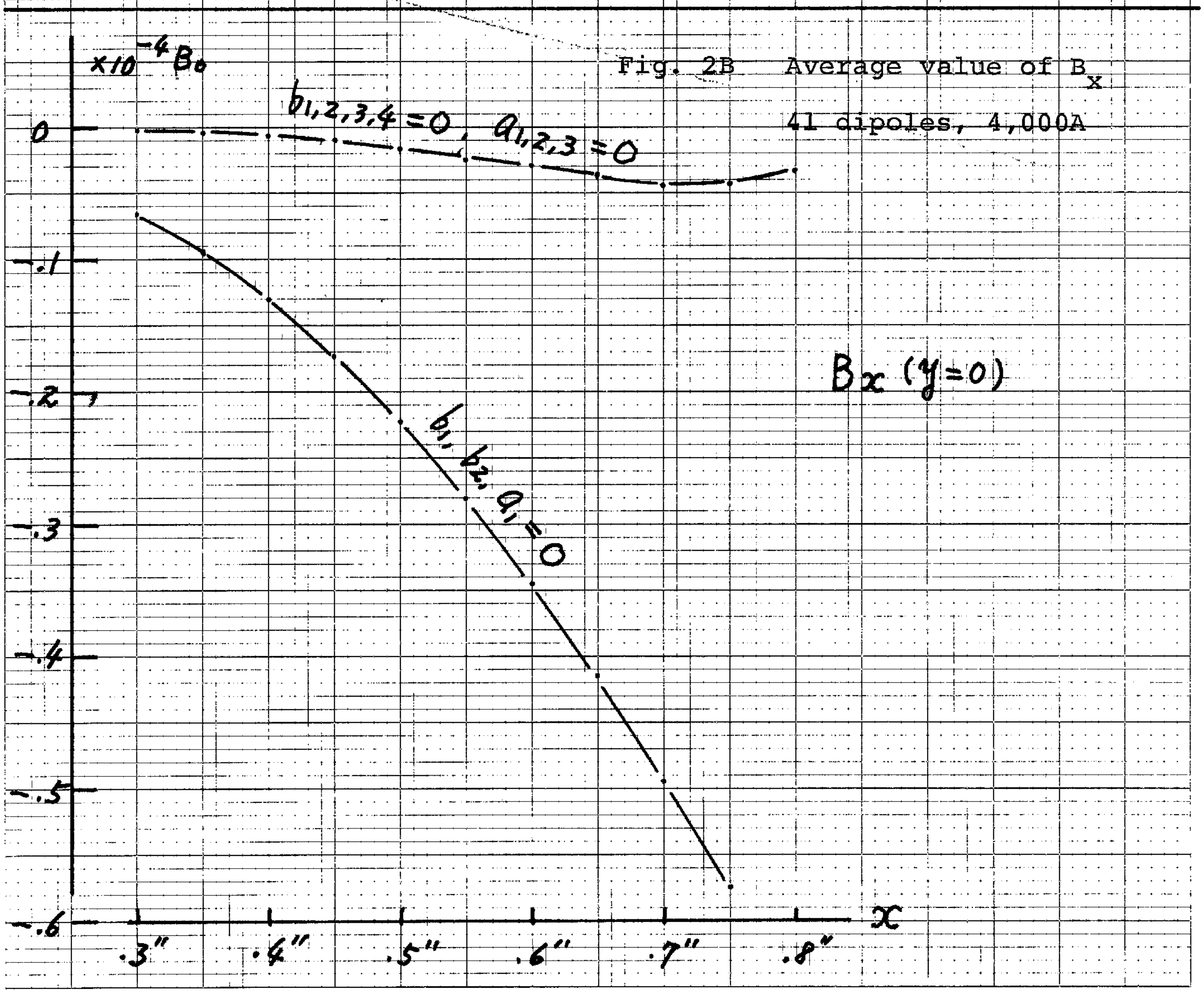


Fig. 2B Average value of B_x
41 dipoles, 4,000A

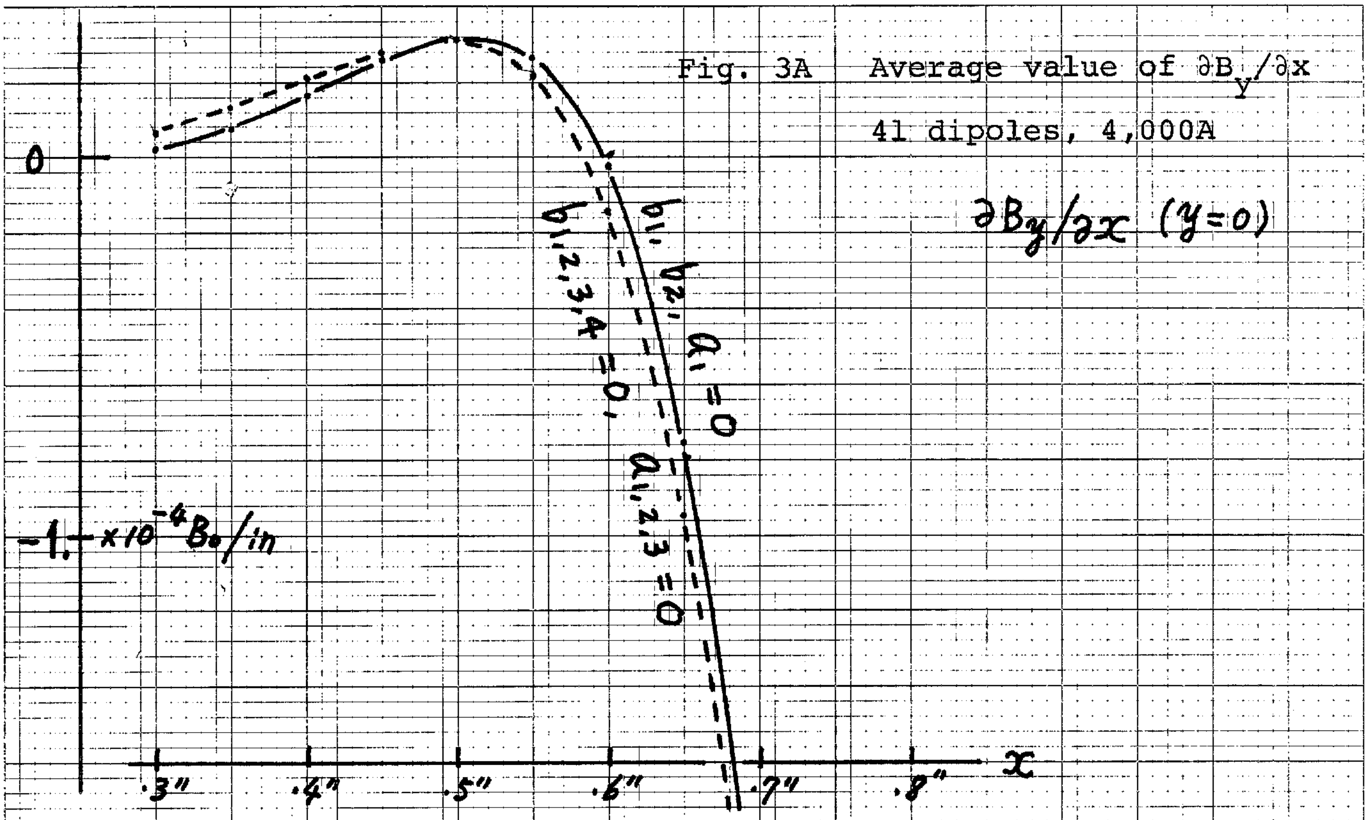
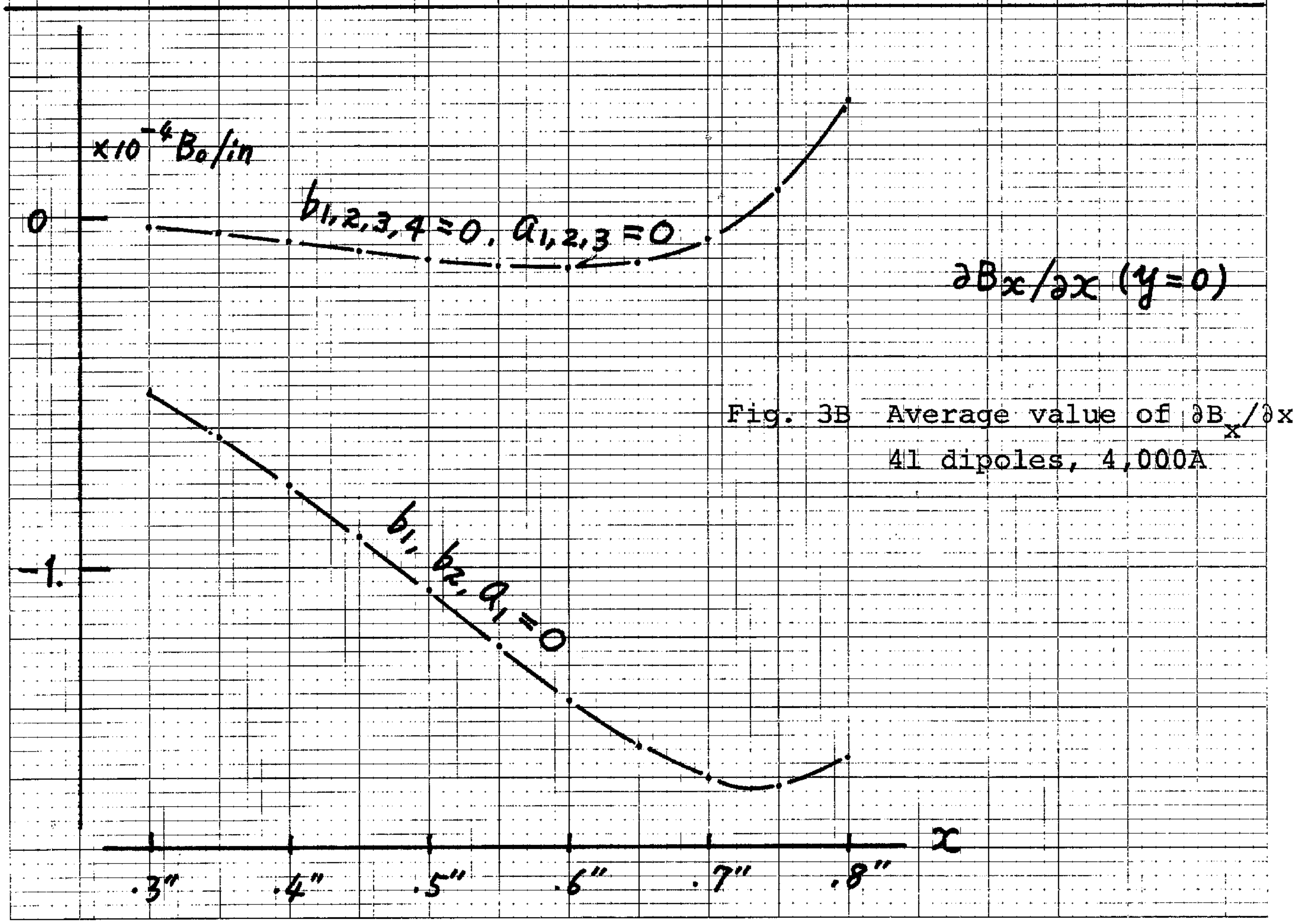


Fig. 3A Average value of $\partial B_y/\partial x$
41 dipoles, 4,000A
$\partial B_y/\partial x$ (y=0)
0
-1.
x10^{-4}B$_0$/in
$b_1, b_2, a_1 = 0$
$b_{1,2,3,4}=0, a_{1,2,3}=0$
.3"
.4"
.5"
.6"
.7"
.8"
x


x10^{-4}B$_0$/in
0
-1.
$b_{1,2,3,4}=0, a_{1,2,3}=0$
$\partial B_x/\partial x$ (y=0)
Fig. 3B Average value of $\partial B_x/\partial x$
41 dipoles, 4,000A
$b_1, b_2, a_1 = 0$
.3"
.4"
.5"
.6"
.7"
.8"
x

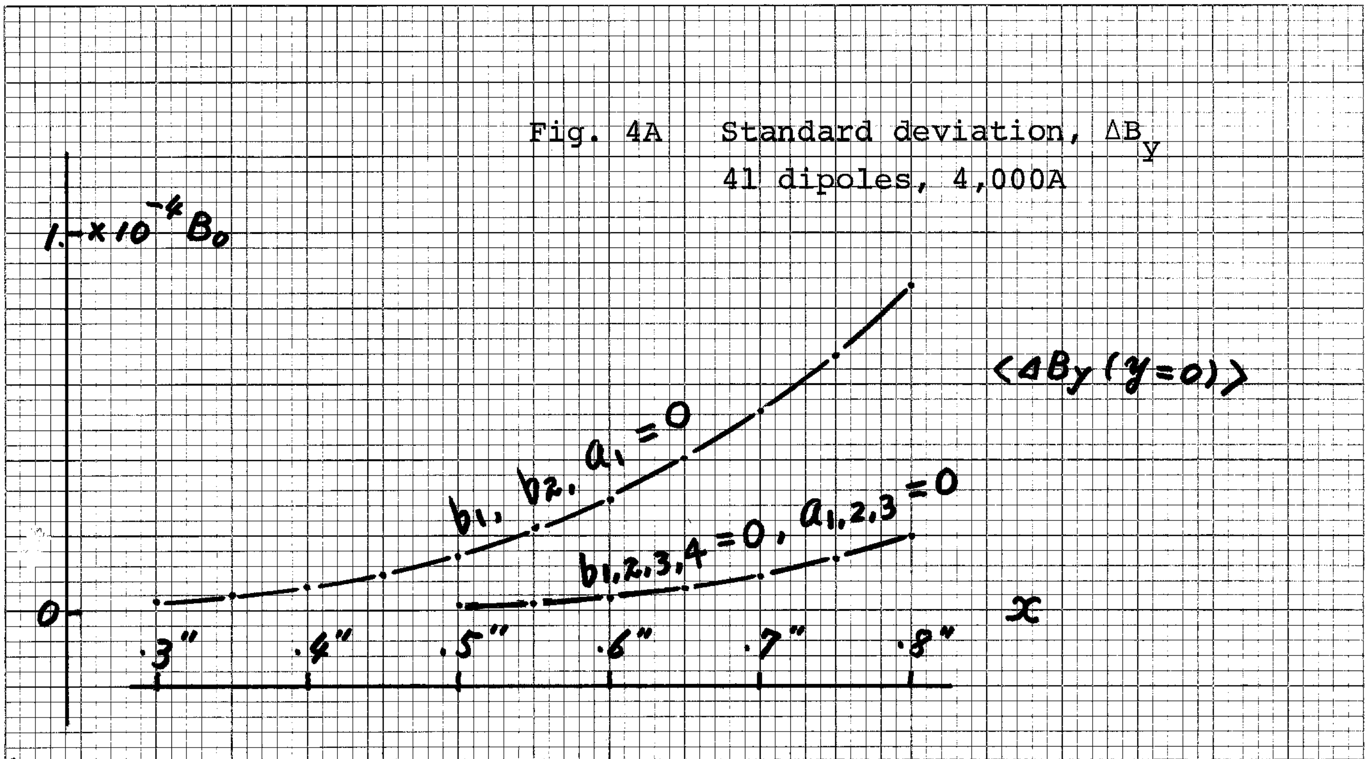


Fig. 4A Standard deviation, ΔB_y
41 dipoles, 4,000A

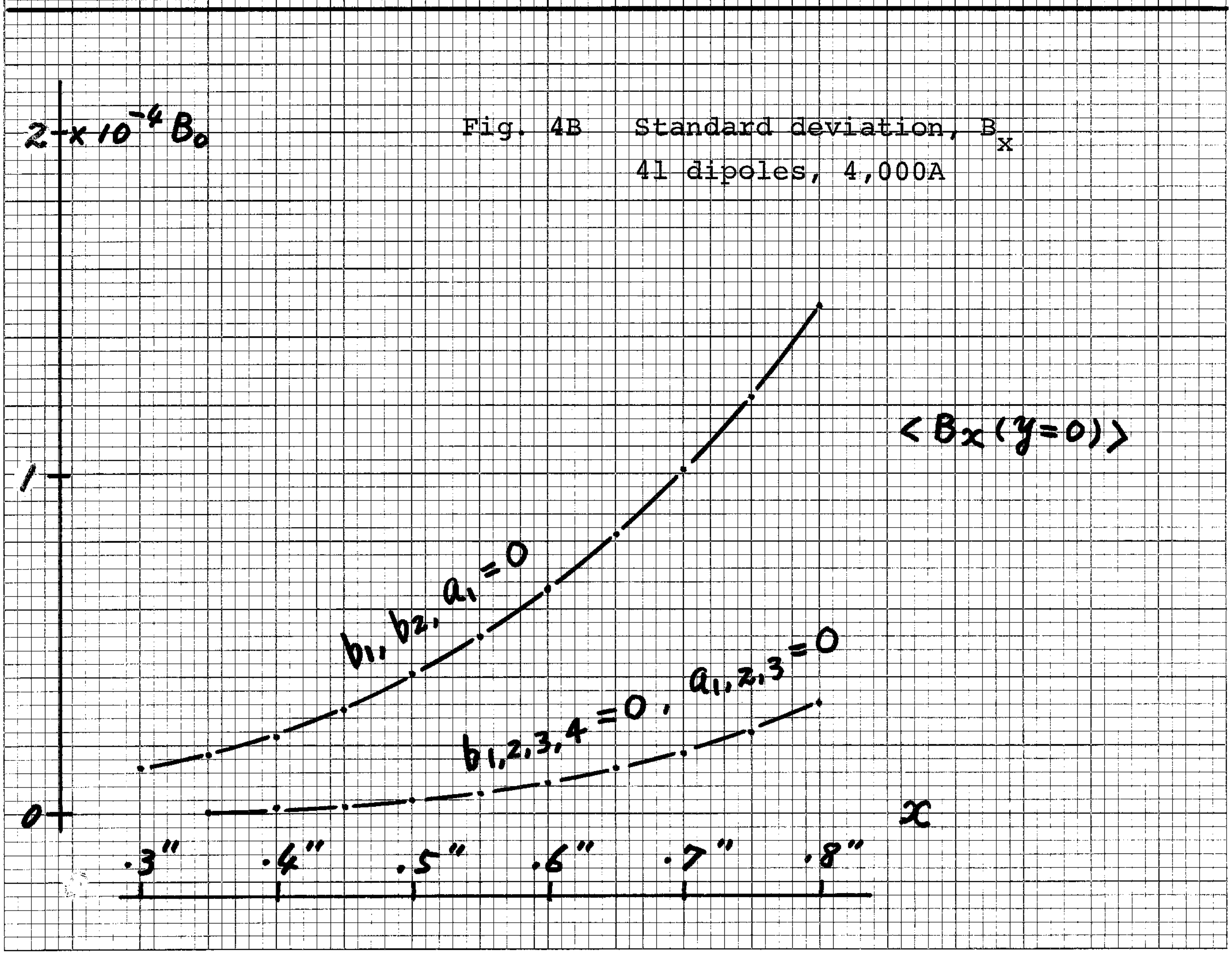
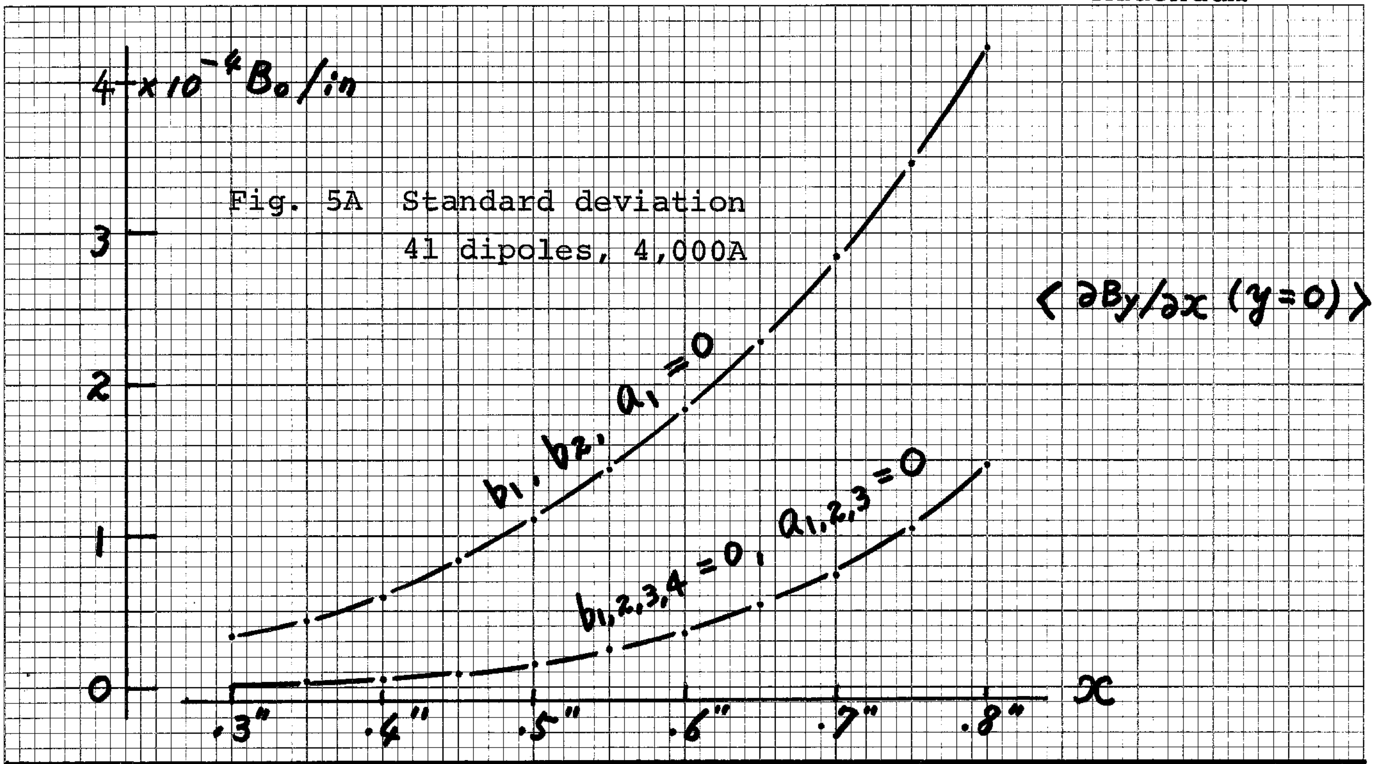
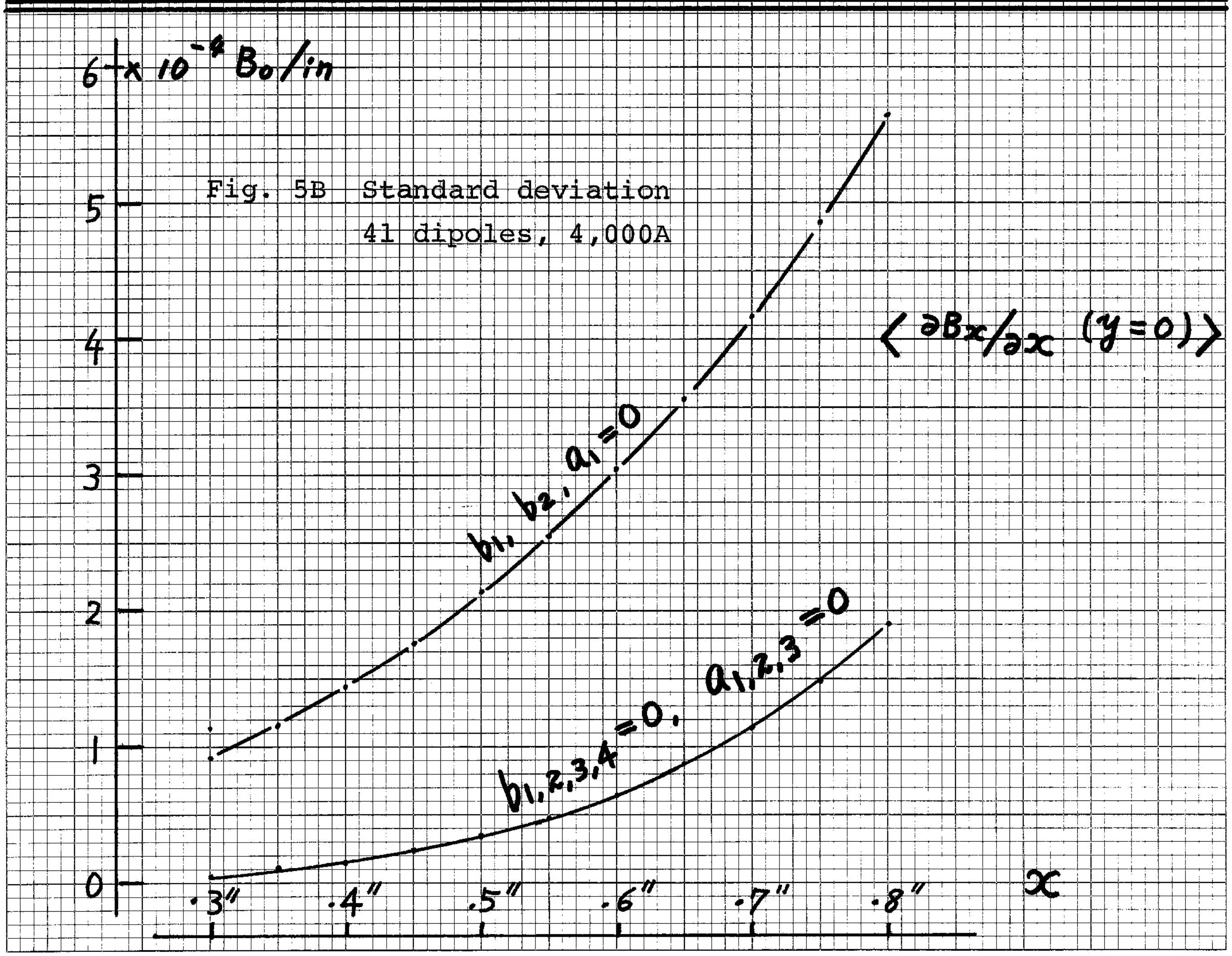


Fig. 4B Standard deviation, B_x
41 dipoles, 4,000A


4 x 10^{-4} B_0/in
3
2
1
0
Fig. 5A Standard deviation
41 dipoles, 4,000A
⟨∂By/∂x (y=0)⟩
b1, b2, a1 = 0
b1,2,3,4 = 0, a1,2,3 = 0
x
.3"
.4"
.5"
.6"
.7"
.8"


6 x 10^{-4} B_0/in
5
4
3
2
1
0
Fig. 5B Standard deviation
41 dipoles, 4,000A
⟨∂Bx/∂x (y=0)⟩
b1, b2, a1 = 0
b1,2,3,4 = 0, a1,2,3 = 0
x
.3"
.4"
.5"
.6"
.7"
.8"